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Small Current-High Voltage Steady-state Operation of MPD Arcjet
定常MPDアークジェットの小電流高電圧作動

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A steady state, applied field, rectangular magnetoplasmadynamics (MPD) thruster with permanent magnets has been developed. The thrust and discharge voltage were measured by varying propellant mass flow rates, discharge current and inter-electrode distance. Setting cathode at exit of the discharge channel, thrust increased and 80-116% of the ideal Lorentz force obtained. Decreasing propellant mass flow rate, the ratio of back EMF to the discharge voltage increased and 16% of the thrust efficiency at 2876sec of specific impulse was obtained.

1. General

A steady state, magnetoplasmadynamic (MPD) thruster is considered one of the most promising high-power thrusters for in space electric propulsion [1]. It has a structural simplicity, high flexibility in propellant species, mass flow rate and specific impulse. However, the most important problems in MPD thruster are low thrust efficiency and short operation time.

A conventional applied field MPD thruster has a coaxial discharge channel, which consisted of a central cylindrical cathode and a concentric axisymmetric anode [2]. On the other hand, Institute of Space and Astronautical Science (ISAS) investigated 2-dimension like applied field MPD thruster have investigated and tested its performance. Introducing rectangular discharge channel, the Lorentz force trends in the same direction as exhaust velocity. As a results, it facilitates the analysis of thruster performance and it has the potential to get higher thrust performance [3]. Generally, the laboratory model high power MPD thruster is operated in quasi steady state, which inputting high current, more than 1 kA, for less than 1 msec . However, the applied field MPD thruster doesn't need such a high current. For example, small current and high voltage can approach high power operation.

Because of these factors, we developed a steady state MPD thruster with a rectangular discharge channel in which electrodes are placed on the upper and lower walls. For better ignition and longer lifetime, a gas fed type hollow cathode is used. The cathode is placed at near the discharge channel exit to distribute discharge current downstream. The purpose of this study is to investigate operational characteristics of the rectangular MPD thruster varying with propellant mass flow rate $\dot{m}$, discharge current J_d and inter electrode distance H.

2. Rectangular MPD thruster head

Figure 1 shows the schematic of the developed rectangular MPD thruster and its electrical circuit. The rectangular discharge channel has a width of 25mm, length in the acceleration direction is 60mm. The inter-electrode distance H, is variable. The upper wall is water cooled anode made of copper. On the lower wall, a hollow cathode (DLHC-1000,

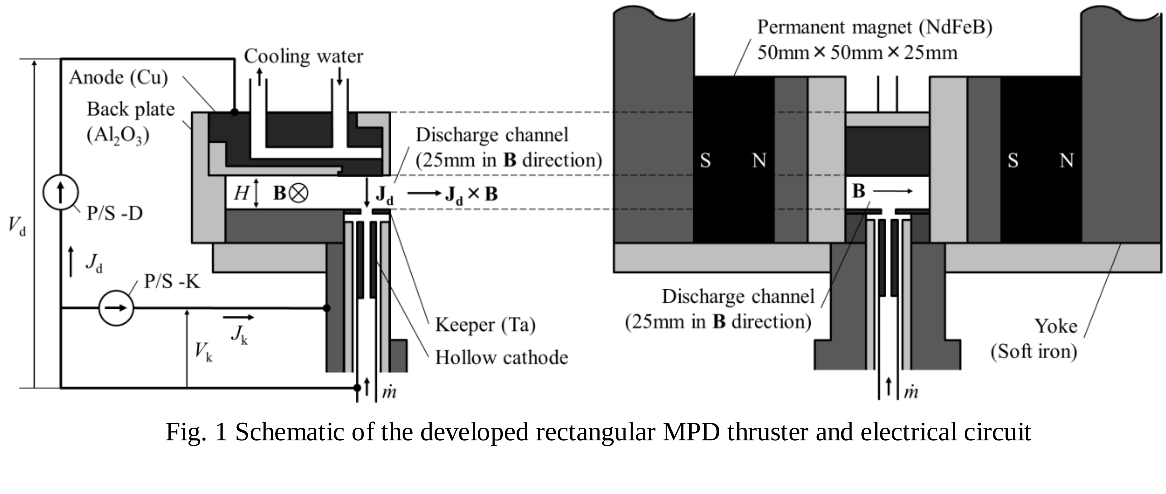

Fig. 1 Schematic of the developed rectangular MPD thruster and electrical circuit

Kaufman & Robinson Inc.) is flush mounted. The keeper electrode is made of 10mm length tantalum plate and cathode tip is set at 5mm upstream from discharge channel exit. An external magnetic field applied in the discharge channel is provided by two neodymium magnets (50mm height, 50mm length in the acceleration direction and 25mm width) connected with an iron yoke. The magnetic field strength was 0.20 T at discharge region.

3. Experimental results

The thruster performance is summarized in Fig. 2. Here, the specific impulse I_{sp} and thrust efficiency η are given by

$$I_{sp} = \frac{F}{\dot{m}g} \tag{1}$$

$$\eta = \frac{F^2}{2\dot{m}J_d V_d} = \frac{F}{J_d BH} \cdot \frac{\bar{u}BH}{V_d} \tag{2}$$

Generally speaking, thrust efficiency is an increasing function of specific impulse. The lower propellant mass flow rate, the higher specific impulse range with high thrust efficiency becomes. The maximum thrust efficiency was 16% at specific impulse was 2876 sec.

Figure. 3 shows the relation between the ideal Lorentz force J_dBH, and measured thrust F. In case that cathode was placed at center of the discharge channel, thrust was lower than the ideal Lorentz force [4]. However, setting cathode at near the discharge channel exit, thrust increased and 80-116% of the ideal Lorentz force obtained. This is because the discharge current distributed outside of the discharge channel and thrust will increase by increasing the magnetic field strength at outside of the discharge channel.

Subsequently, the ratio of back EMF to discharge voltage $\bar{u}BH/V_d$ is shown in Fig. 4. As decreasing propellant mass flow rate, $\bar{u}BH/V_d$ increased. This is because that effective exhaust velocity increased as decreasing propellant mass flow rate.

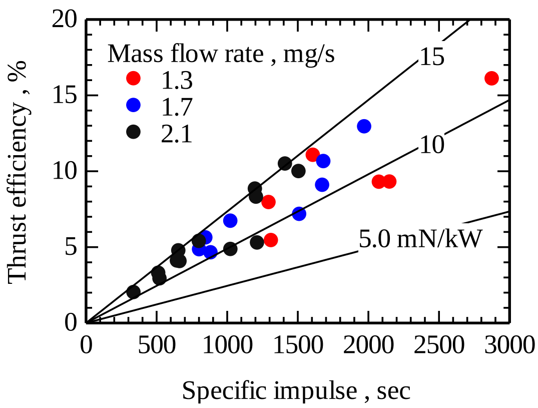

Fig. 2 Thrust efficiency as a function of specific impulse (J_d=5.0-15A, B=0.20T, H=10,15mm)

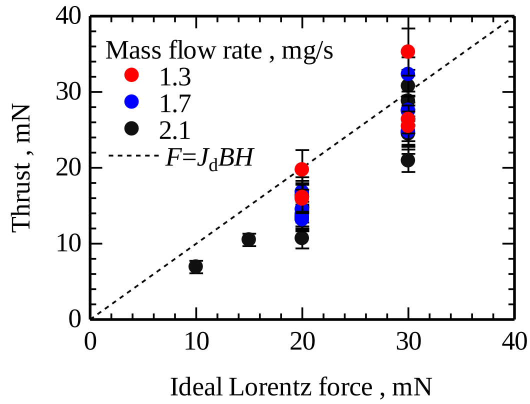

Fig. 3 Thrust vs ideal Lorentz force (J_d=5.0-15A, B=0.20T, H=10,15mm)

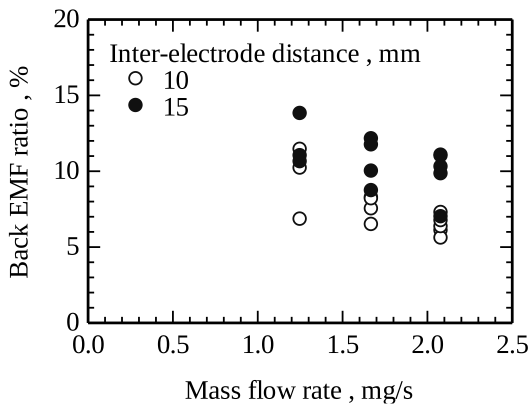

Fig. 4 Back EMF ratio vs mass flow rate (J_d=10A, B=0.20T)

4. Conclusion

By setting cathode at near the discharge channel exit, thrust increased and 80-116% of the ideal Lorentz force was obtained. As decreasing propellant mass flow rate, the ratio of back EMF to discharge voltage increased. Decreasing mass flow rate also increased thrust efficiency and maximum thrust efficiency 16% was obtained at specific impulse was 2876 sec.

References

[1]. K. Sankaran, L. Cassady, A. D. Kodys and E. Y. Choueiri: Annals of the New York Academy of Sciences. **1017** (2004). 450.

[2]. G. Krulle, M. A. Kurtz and A. Sasoh: *J.P.P.* **14** (1998). 754.

[3]. A. Iwakawa, D. Nakata, and H. Kuninaka: *Proc. 31th International Electric Propulsion Conference, Michigan, 2009*, IEPC-2009-226.

[4]. S. Yokota, D. Ichihara, H. Kataoka, S. Harada and A. Sasoh: *Proc. 33th International Electric Propulsion Conference, Washington, 2013*, IEPC-2013-246.